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Simultaneous lightness contrast with double increments

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Abstract. In this paper we demonstrate the existence of simultaneous lightness contrast in displays in which the target patches are both more luminant than their surrounds. These effects are not predicted by theories of lightness that assume that the highest luminance in a scene is perceived as white, and anchors all the other luminances. We show that the strength of double-increment illusions depends crucially on the luminance of both the surrounds and the target patches. Such luminance prerequisites were not met in previous studies, which explains why simultaneous contrast with incremental targets has so far been regarded as extremely weak or nonexistent.

1 Introduction

A grey patch set against a dark background looks lighter than an identical grey patch set against a light background. This well-known effect, simultaneous lightness contrast, is at its best when the twin greys of the patches are more luminant than the dark background and less luminant than the light background—that is, when they represent an increment in one case and a decrement in the other, as in the top display of figure 1. A weaker effect also obtains when the two target greys are both decrements (ie darker than their backgrounds), as in the middle display, but no appreciable illusion has been reported when they are both increments, as in the bottom display (Diamond 1953; Heinemann 1955; Gilchrist 1988; Arend and Spehar 1993).

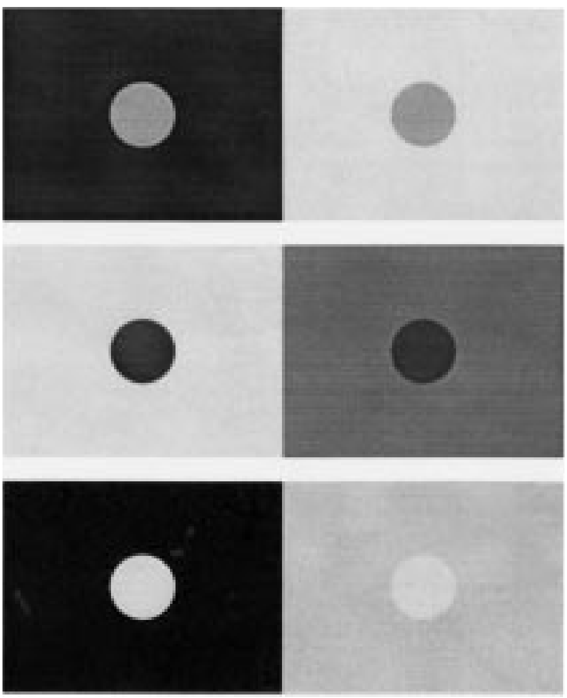

Figure 1. Simultaneous lightness contrast with one increment and one decrement (top), with two decrements (middle), and with two increments (bottom).

The absence of simultaneous contrast with double increments is actually predicted by the anchoring theory of lightness (Gilchrist et al 1999). The theory says that a visual scene is divided into perceptual groups, or frameworks, on the basis of Gestalt grouping principles. The lightness of any given surface is a weighted average of two lightness values, computed within two different frameworks: a local one and a global one. (The principle can, of course, be extended to any number of frameworks.) Within each framework, the role of anchor is always assigned to the highest luminance, which is given a value of white, and all other regions will be perceived as shades of grey, depending on their luminance ratio to such white. An additional rule is that any area that takes up more than half of the visual field tends to lighten, and the larger it becomes the lighter it appears.

In the global framework of figure 1 (top display), which includes both rectangles and both discs, the light rectangle on the right works as an anchor, and the two discs are assigned identical grey values relative to it. Locally, however (that is in each of the frameworks including one rectangle and the disc sitting on it), the lightness assignments are different for the two target discs: grey for the one on the right (which is compared to the same anchor), white for the one on the left, that being the highest luminance in its local framework works as the local anchor. Thus the target on the light background is globally grey and locally grey; the target on the dark background is globally grey and locally white, yielding a perceptually lighter grey.

Let us consider now the bottom display. The two incremental targets have identical lightness assignment not only globally but also locally, because each is the highest luminance within its local framework. Both targets will thus be computed as white, regardless of their ratio to the luminance of their immediate surrounds. According to the model, then, the two targets ought to appear identical: but do they? According to the available evidence (Gilchrist 1988; Arend and Spehar 1993), they do; yet informal demonstrations of simultaneous contrast with incremental targets have been presented (Bressan 2001), and appear to contradict such conclusions.

In this paper we will discuss double-increment illusions, first by proving experimentally that they exist, and second by showing that the reason why they have previously gone unnoticed is that their luminance prerequisites were, in those studies, never met.

2 Experiment 1

2.1 *Methods*

2.1.1 *Subjects.* Twenty observers (ten females and ten males) took part in the experiment. They had normal or corrected-to-normal vision.

2.1.2 *Apparatus and stimuli.* Stimuli were generated by a PC on a 17-inch NEC MultiSync P750 screen. Each stimulus consisted of two uniform surrounds placed side by side, each 16 deg × 21.9 deg (they took up the entire screen). A 0.7 deg × 0.7 deg square test patch was centred within one of these surrounds, which was always black (0.99 cd m^{-2}). The initial luminance of the test patch was set to 39.87 cd m^{-2}. A 0.7 deg × 0.7 deg square comparison patch was centred within the other surround. The luminances of the comparison patch and of its surround were varied over trials in a random order. The comparison patch always represented a luminance increment relative to its surround, and could assume four possible values: 66.05 cd m^{-2} (presented on surrounds of 3.49, 8.63, 16.61, 27.54, 41.38, and 58.38 cd m^{-2}); 47.82 cd m^{-2} (presented on surrounds of 3.49, 8.63, 16.61, 27.54, and 41.38 cd m^{-2}); 32.71 cd m^{-2} (presented on surrounds of 3.49, 8.63, 16.61, and 27.54 cd m^{-2}); 20.59 cd m^{-2} (presented on surrounds of 3.49, 8.63, and 16.61 cd m^{-2}), for a total of 18 different stimuli. All luminances were measured with a Minolta Luminance Meter LS100 photometer.

The experiment was divided into two sessions: in the first, the surround with the test patch was always displayed on the right half of the monitor; in the second, it was displayed on the left side. Each stimulus was shown twice (once on the right side and once on the left side), for a total of 36 trials. Before each session, written instructions were presented on the screen.

2.1.3 *Procedure.* Observers viewed the monitor at a distance of 60 cm in a dimly lit room. They used the method of adjustment: they varied the luminance of the test patch (the one on the black background) to match the achromatic colour of the comparison patch (the one on the variable background). The instructions referred to the achromatic colour (shade of grey) of the patches, rather than to their lightness or brightness. Observers pressed the '+' key to increase the patch luminance and the '−' key to decrease it; when they were satisfied with their match, they pressed the return key to start the next trial.

2.2 *Results and discussion*

Figure 2 shows the luminance matches for the test patch, averaged for each subject across the right-side and left-side presentations, as a function of the luminance of the comparison patch. The diagonal dashed line represents the prediction for perfect luminance matching. As can be seen, the luminance values that the observers chose for the test patches were always smaller than those of the corresponding comparison patches. Since the test patch sat on black, this means that, in our experimental conditions, an incremental patch on a black surround looked always lighter than an identical incremental patch on any other surround.

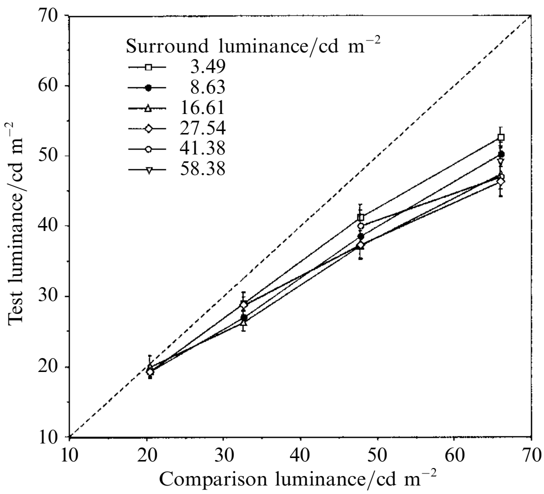

Figure 2. Test luminance plotted as a function of comparison luminance, for six luminances of the surround (experiment 1). The diagonal dashed line shows the objective luminance matching. Each data point is an average across twenty observers and two trials. Bars indicate the standard error of the mean.

In figure 3, the same results are illustrated by plotting the test luminance against the luminance of the surround, rather than against the luminance of the comparison patch. The parallel dashed lines represent perfect luminance matchings, for each of the four targets; the leftmost point in each data line depicts the point of objective equality. The graph shows that the luminance values that the observers chose for the test patches tended to decrease with increasing surround luminance.

Note that, for the top three curves, the rightmost points, which correspond to target/surround luminance ratios close to 1 (ranging from 1.13 to 1.24), tend to rise slightly. In other words, if we set a light patch against a black surround and then gradually increase the surround luminance, the patch will look progressively darker, but this trend will reverse as soon as the surround luminance becomes nearly as high as the patch luminance. We interpret such reversal in terms of crispening effect (see

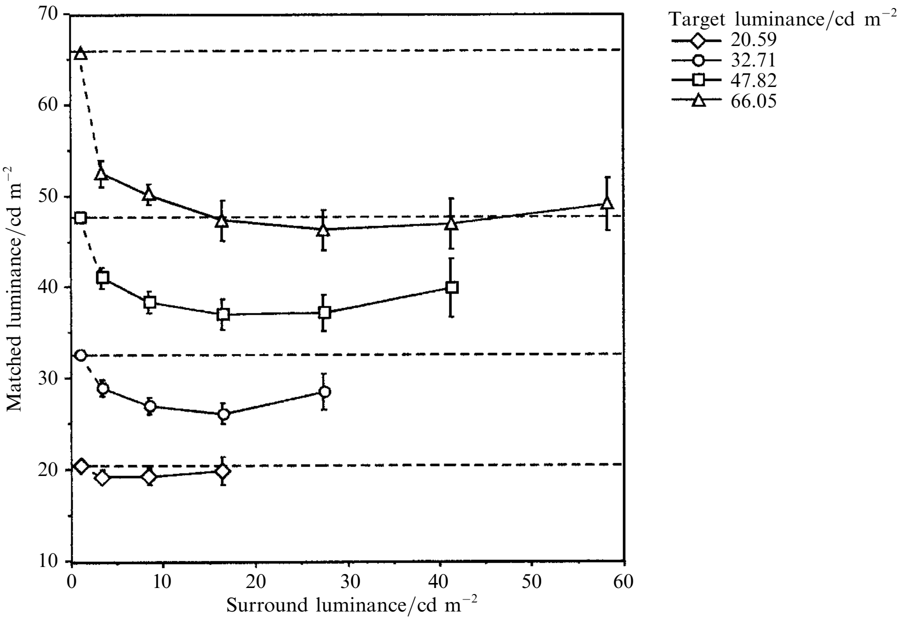

Figure 3. Test luminance plotted as a function of surround luminance, for four luminances of the target (experiment 1). The dashed lines show the objective luminance matchings for the four targets (from 20.59 to 66.05 cd m^{-2}, bottom to top); the leftmost point in each data line represents the point of objective equality. Each data point is an average across twenty observers and two trials. Bars indicate the standard error of the mean.

Whittle 1992). The difference between a target and its background is exaggerated when the target luminance is close to the luminance of the background. An incremental target, then, will tend to lighten, which will contrast its tendency to darken (relative to an identical target on a black surround). For this reason, we excluded the data corresponding to the rightmost points of the curves before testing, separately for each target luminance, the effect of luminance of the comparison surround.

The mean matching luminances were converted into percentage errors, that is into deviations from the objectively matching luminances. The effect of luminance of the comparison surround proved significant or marginally significant for all targets but the lowest-luminance one ($F < 1$): respectively, $F_{2,38} = 5.6$, $p = 0.007$ for 32.71 cd m^{-2} targets; $F_{3,57} = 2.27$, $p = 0.09$ for 47.82 cd m^{-2} targets; $F_{4,76} = 2.64$, $p = 0.04$ for 66.05 cd m^{-2} targets. Rounded average errors for 3.49, 8.63, 16.61, 27.54, and 41.38 cd m^{-2} surrounds amounted, respectively, to 13%, 16%, 18%, 21%, and 22%.

Figure 3 shows clearly that, proceeding from the bottom to the top curve, the vertical distance between each curve and the corresponding dashed line increases: this means that double-increment illusions increase with target luminance. The effect of luminance of the comparison patch proved indeed significant for each of the five surrounds: respectively, $F_{3,57} = 5.70$, $p = 0.002$ for the 3.49 cd m^{-2} surround; $F_{3,57} = 8.48$, $p < 0.0001$ for the 8.63 cd m^{-2} surround; $F_{3,57} = 8.89$, $p < 0.0001$ for the 16.61 cd m^{-2} surround; $F_{2,38} = 8.73$, $p = 0.001$ for the 27.54 cd m^{-2} surround; $F_{1,19} = 6.22$, $p = 0.02$ for the 41.38 cd m^{-2} surround. Rounded average errors for 20.59, 32.71, 47.82, and 66.05 cd m^{-2} comparison patches were, respectively, 5%, 15%, 19%, and 26%. The 5% error for the 20.59 cd m^{-2} patch was not significantly different from zero, one-sample $t_{19} = 1.66$, ns.

3 Experiment 2

In the first experiment, the initial luminance of the test patch was set to 39.87 cd m^{-2}, so that subjects had to increase it when the comparison patches were 47.82 and 66.05 cd m^{-2}, and decrease it when the comparison patches were 32.71 and 20.59 cd m^{-2}. Now, here the contrast effect is expressed as the choice of a test luminance lower than the comparison luminance. On the assumption that subjects are less than perfect discriminators and that they may tend to end the adjustment process as soon as they reach a satisfactory match (ie to stop too soon), the choice of a luminance that is too low will be more likely when luminance is low to start with, and subjects have to increase it, rather than the opposite. Indeed, we did find stronger contrast effects with higher-luminance patches. We then decided to run a second experiment, to check whether this asymmetry could, at least in part, be responsible for the dependence of illusion magnitude on the luminance of the target. In this experiment, observers performed two full sets of adjustments, starting once from a low luminance and once from a high luminance of the test patch. The test patch was still sitting on black, but this time we added a baseline condition in which the comparison patch was also presented on a black surround.

3.1 *Methods*

3.1.1 *Subjects.* Ten observers (five females and five males) participated in the experiment. They had normal or corrected-to-normal vision.

3.1.2 *Apparatus and stimuli.* Stimuli were generated by a PC on a 17-inch Philips Brilliance 105 screen. Each stimulus consisted of two uniform surrounds placed side by side, each 16 deg $\times$ 21.9 deg (they took up the entire screen). A 0.7 deg $\times$ 0.7 deg square test patch was centred within one of these surrounds, which was always black (0.30 cd m^{-2}). A 0.7 deg $\times$ 0.7 deg square comparison patch was centred within the other surround. The luminances of the comparison patch and of its surround were varied over trials in a random order. The comparison patch always represented a luminance increment relative to its surround, and could assume four possible values: 93.76 cd m^{-2} (presented on surrounds of 0.30, 2.97, 10.63, 23.50, 41.25, and 66.18 cd m^{-2}); 77.08 cd m^{-2} (presented on surrounds of 0.30, 2.97, 10.63, 23.50, 41.25, and 66.18 cd m^{-2}); 51.34 cd m^{-2} (presented on surrounds of 0.30, 2.97, 10.63, 23.50, and 41.25 cd m^{-2}); 29.75 cd m^{-2} (presented on surrounds of 0.30, 2.97, 10.63, and 23.50 cd m^{-2}), for a total of 21 different stimuli. All luminances were measured with a Minolta Luminance Meter LS100 photometer.

Each experimental session was divided into two parts: in the first, the surround with the test patch was always displayed on the right half of the monitor; in the second, it was displayed on the left side. Each stimulus was shown twice (once on the right side and once on the left side), for a total of 42 trials. At the beginning of each session, written instructions were presented on the screen. The experiment consisted of two separate sessions (presented in counterbalanced order): the initial luminance of the test patch was 23.5 cd m^{-2} in one, 106.4 cd m^{-2} in the other.

3.1.3 *Procedure.* Sessions were run in the dark. At each presentation of the stimulus, observers were also asked to report whether any of the patches appeared luminous. In all other respects, the procedure was identical to that used in experiment 1.

3.2 *Results and discussion*

Figure 4 illustrates the results of experiment 2, with the test luminance plotted against the luminance of the surround, as in figure 3. Luminance matches have been averaged across the right-side and left-side presentations and the initial luminance of the test. The parallel dashed lines represent perfect luminance matchings, for each of the four targets; this time, the leftmost point in each data line depicts the point of subjective equality.

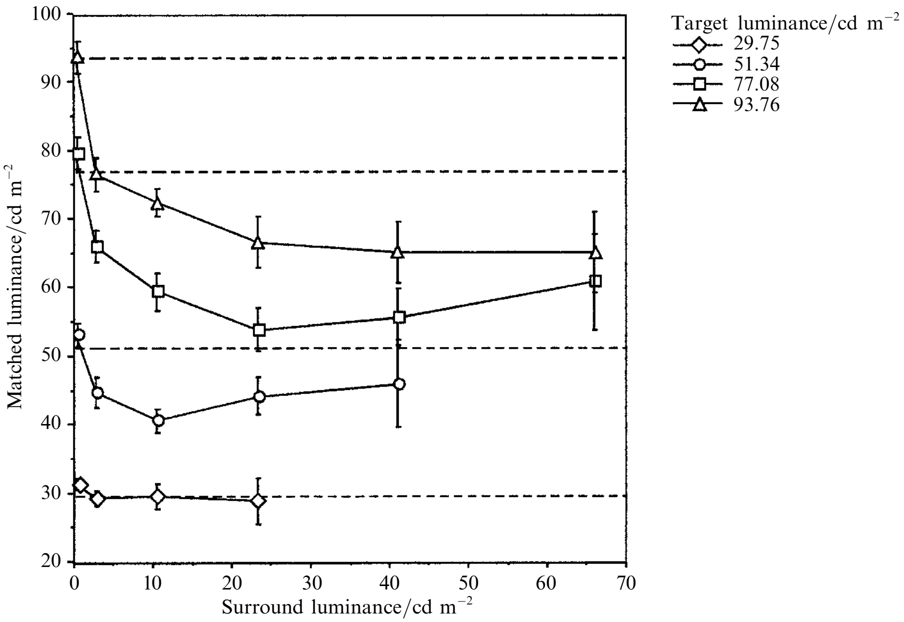

Figure 4. Test luminance plotted as a function of surround luminance, for four luminances of the target (experiment 2). The dashed lines show the objective luminance matchings for the four targets (from 29.75 to 93.76 cd m^{-2}, bottom to top). Each data point is an average across ten observers and four trials. Bars indicate the standard error of the mean.

As can be seen, the luminance values that the observers chose for the test patches tended to decrease with increasing surround luminances, for all targets but the least luminant one (bottom). The top three curves flatten around the data point corresponding to the highest luminance surrounds, and for the two middle curves the direction of the illusion even tends to reverse. Since the rightmost points of such curves correspond to very low target/surround luminance ratios (respectively 1.16 and 1.24), we suggest, again, that such reversal be due to the contrasting influence of a crispening effect, as in experiment 1.

The mean matching luminances were converted into percentage errors. We tested, separately for each target luminance, the effects of initial luminance of the test patch (two levels: 23.5 and 106.4 cd m^{-2}) and luminance of the comparison surround. Errors increased with surround luminance. The latter proved significant or marginally significant for all targets but the lowest-luminance one ($F < 1$): respectively, $F_{4,36} = 2.28$, $p = 0.08$ for 51.34 cd m^{-2} targets; $F_{5,45} = 9.18$, $p < 0.0001$ for 77.8 cd m^{-2} targets; $F_{5,45} = 13.57$, $p < 0.0001$ for 93.76 cd m^{-2} targets. Neither the initial luminance of the test patch nor its interaction with the luminance of the comparison surround were significant for any of the four targets. Average errors for 0.30, 2.97, 10.63, 23.50, 41.25, and 66.18 cd m^{-2} surrounds were, respectively, −3%, 11%, 16%, 19%, 23%, and 26%.

We then tested, separately for each of the six surround luminances, the effects of initial luminance of the test patch and luminance of the comparison target. Errors increased with luminance of the comparison target. The latter was significant or marginally significant in all cases, except for the 0.30 cd m^{-2} (black) surround ($F < 1$): respectively, $F_{3,27} = 5.03$, $p = 0.007$ for 2.97 cd m^{-2} surrounds; $F_{3,27} = 10.04$, $p < 0.0001$ for 10.63 cd m^{-2} surrounds; $F_{3,27} = 7.18$, $p = 0.001$ for 23.50 cd m^{-2} surrounds; $F_{2,18} = 4.00$, $p = 0.036$ for 41.25 cd m^{-2} surrounds; $F_{1,9} = 4.60$, $p = 0.06$ for 66.18 cd m^{-2} surrounds. For all non-zero surrounds, the initial luminance of the test patch was nonsignificant (Fs < 1.2). For the 0.30 cd m^{-2} surround, we found a marginally significant effect of initial luminance, $F_{1,9} = 3.58$, $p = 0.09$. This was due to a slight but significant negative error when the initial luminance was 23.5 cd m^{-2} (−6.6%, one-sample $t_9 = 2.57$, $p = 0.03$), but not when the initial luminance was 106.4 cd m^{-2} (−0.12%, one-sample $t < 1$). In other words, when subjects had to increase the initial luminance of the test patch (always on black) to match that of a comparison patch also sitting on black, they tended to adjust more than necessary and settle on a luminance that was too high. This happened for all comparison patches. There was no bias, for any of the comparison patches, when the initial luminance had to be decreased, rather than increased. The interaction of initial target luminance with the luminance of the comparison target was never significant (all Fs < 1).

Rounded average errors for 29.75, 51.34, 77.08, and 93.76 cd m^{-2} comparison patches were equal to 1%, 14%, 23%, and 26%. If, for each target, the mean error for the target on black is subtracted from all the other data, to give measures of illusion magnitude relative to the point of subjective equality, such errors become, respectively, 7%, 18%, 26%, and 26%. (The 7% error for the 29.75 cd m^{-2} patch is not significantly different from the 15% error for the 32.71 cd m^{-2} patch of experiment 1, independent-samples $t_{28} = 1.3$, ns.)

We should add that the task was considered a difficult one: in both experiments subjects often reported that the match was not entirely satisfactory, and that there was still a residual difference in visual quality between the patch lying on black and the patch lying on the variable surround. Our least luminant target on the most luminant of its surrounds (29.75 cd m^{-2} on 23.50 cd m^{-2}) was regarded as especially hard to match because of its peculiar appearance, which was described as 'foggy'. As to luminosity reports, our two most luminant targets (77.08 and 93.76 cd m^{-2}) were unanimously reported as luminous when presented on the black surround (0.30 cd m^{-2}), but not on any other surrounds. None of the other targets was perceived as luminous.

In conclusion, experiment 2: (a) showed that the dependence of the effect on target luminance found in experiment 1 was not an artifact due to the contingency that the luminance of the adjustable patch needed to be decreased in some cases and increased in others; (b) complemented (with the comparison patch presented on black) and replicated the results of experiment 1.

4 General discussion

We found that the perceptual darkening of an incremental patch sitting on any non-black surround, relative to an identical patch sitting on black, is an increasing function of surround luminance, and an increasing function of patch luminance. The first result suggests that increments and decrements are affected by their backgrounds in similar ways, as claimed by Heinemann (1989). The second result indicates that the contrast illusion observed with increments is, in some respects, different from classical simultaneous lightness contrast, where the effect is a decreasing, rather than increasing, function of patch luminance (as shown for instance by Economou et al 1999). The theoretical reasons for this difference are complex; their discussion goes beyond the scope of this paper, and is presented as a part of a new model of lightness in Bressan (in preparation).

These experiments are apparently the first empirical report of clear simultaneous contrast effects in regions that represent a luminance increment relative to their surrounds. Yet, we believe that these data are not in contradiction with previous failures to find a (lightness or brightness) contrast effect with double increments, such as those of Heinemann (1955), Gilchrist (1988), Arend and Spehar (1993), and Diamond (1953).

Heinemann (1955) found no contrast effects for incremental discs surrounded by either darkness or annuli of variable luminance; but all his target luminances were lower than 1.65 log mL, ie 14 cd m^{-2}, a value that according to our data is far too low to yield a double-increment illusion. In experiment 1 we found no significant effect with comparison patches of luminance as high as 20.59 cd m^{-2}.

Gilchrist (1988) failed to find a simultaneous contrast illusion with paper patches of 85.6 cd m^{-2} against a dark and a light surround of respectively 10.6 and 41.1 cd m^{-2}. Our data are not at all in disagreement with such finding. A 85.6 cd m^{-2} patch would fall approximately midway between our two most luminant targets in experiment 2 (77.08 and 93.76 cd m^{-2}). By interpolation, the average errors for a 85.6 cd m^{-2} target against surrounds of 10.63 and 41.25 cd m^{-2} would be respectively 23% and 29%—a 6% difference. That is, although two 85.6 cd m^{-2} targets on a 10.63 and a 41.25 cd m^{-2} surrounds look both much darker than an identical target on a black surround (as can be seen in figure 4), the extents to which they do are not significantly different, $t_9 = 1.8$, ns. Note, too, that an effect that is just barely noticeable on a monitor in the dark may well become imperceptible with paper stimuli observed in a classroom, as in Gilchrist's experiment. In paper-and-illuminant displays, simultaneous contrast illusions have been shown to be reduced by half (Agostini and Bruno 1996). On the basis of the results of our experiments, one would predict that, if the dark surround in Gilchrist's demonstration had been black, rather than dark grey, the simultaneous contrast effect would have been unmistakable.

Arend and Spehar (1993) reported no contrast illusions with increments for test patches (subtending 1 deg of visual angle) sitting on a uniform surround (3 deg) surrounded in turn by a Mondrian, that is a patchwork of small rectangles of various luminances (5 deg). However, they did find some dependence of the patch lightness on surround luminance when the Mondrian portions were replaced by an enlarged, uniform surround of the same luminance as the inner surround. Such effect, that they describe as 'slight', is certainly much smaller than the one observed with decrements, and only obtains in two subjects out of three (see their figure 6). Yet, the actual patch luminance used in those experiments (1.47 cd m^{-2} in log luminance, corresponding to 29.5 cd m^{-2}) would fall between the two lowest curves in our figure 2, supporting, at best, an illusion quite weak compared with those that can be observed with more luminant patches. Indeed, the contrast effect we found in experiment 2 with our 29.75 cd m^{-2} comparison patch failed to reach statistical significance.

Diamond (1953) concluded that the brightness of an incremental test field decreased relatively little as the luminance of an inducing field was increased. However, only two of his test fields had a luminance higher than 14 cd m^{-2}: 2.17 and 2.71 log mL, corresponding to about 46.5 and 161 cd m^{-2}. On the basis of Diamond's data (averages over two subjects), a small, but consistent simultaneous contrast effect can indeed be demonstrated with his highest-luminance target. A 161 cd m^{-2} patch surrounded by darkness, ie zero luminance, looked always brighter than an identical, incremental patch adjacent to an inducing field of non-zero luminance. This was true for all of the seven inducing fields used by Diamond. The fact that the average error was small (about 6%), and was observed for the 161 cd m^{-2} but not for the 46.5 cd m^{-2} patch, is easily accounted for by the stimulus configuration. The inducing field had the same size as the test patch (rather than being much larger, as in our experiments), and was adjacent to it on one side only (rather than completely surround it, as in our experiments).

Our results are also consistent with the data by Flock and Noguchi (1973). Their stimulus configuration was not as clean as one may wish, since it contained seven different patches, arranged in a cross. This means that each patch was affected not only by the common surround, but also by the other patches. The cross was presented under different illuminations and on three separate surrounds (black, grey, and white).

We would expect a sizeable effect of background luminance on the brightness of incremental patches above a certain luminance value (say, not lower than 20 cd m^{-2}), and adjacent to such background on more than two sides. The patches that met these requirements, under the three highest illumination levels and against the black and grey backgrounds, were two: the square at the top of the vertical shaft of the cross (labelled as T in Flock and Noguchi 1973) and the square on the right in the horizontal shaft (labelled as R). In all six cases (two patches by three illumination levels), the patch on the black background looked obviously brighter than the identical patch on the grey background (see Flock and Noguchi 1973, figure 3). It is interesting to note that, for both patches, but especially for T (that, unlike R, was incremental on all sides), this difference increased with target luminance.

In conclusion, then, it appears that previous failures to observe double-increment illusions were due to the specific luminances used in those experiments, and more precisely to a surround too luminant (as in Gilchrist 1988) or a target not luminant enough (as in Heinemann 1955, and Arend and Spehar 1993); and, in at least one case (Diamond 1953), to an unfavourable stimulus configuration.

The existence of double-increment illusions is clearly crucial for future developments of the anchoring theory of lightness. Although the theory cannot at present accommodate such effects, we believe that these can in fact be predicted within a slightly modified version of it, where anchoring is replaced by double anchoring (Bressan, in preparation). In this perspective, within each framework objects are independently anchored to the highest luminance and to the average luminance of their surround. The lightness value of a region in a framework is the weighted average of the ratios computed at the two steps. Incremental targets in displays such as that of figure 1, then, are still assigned identical values of white, but are also assessed in relation to their immediate surrounds and locally given additional lightness values that are not equal, resulting in whiter whites for blacker surrounds.

References

Agostini T, Bruno N, 1996 "Lightness contrast in CRT and paper-and-illuminant displays" *Perception & Psychophysics* **58** 250–258

Arend L E, Spehar B, 1993 "Lightness, brightness, and brightness contrast: 2. Reflectance variation" *Perception & Psychophysics* **54** 457–468

Bressan P, 2001 "Explaining lightness illusions" *Perception* **30** (forthcoming)

Bressan P (in preparation) *The Place of White in a World of Greys: A Double-Anchoring Theory of Lightness Perception*

Diamond A L, 1953 "Foveal simultaneous brightness contrast as a function of inducing- and test-field luminances" *Journal of Experimental Psychology* **45** 304–314

Economou E, Donnaruma M, Gilchrist A, 1999 "Further evidence for an anchoring account of simultaneous lightness contrast" *Perception* **28** Supplement, 34b

Flock H R, Noguchi K, 1973 "Brightness functions for a complex field with changing illumination and background" *Canadian Journal of Psychology* **27** 16–38

Gilchrist A L, 1988 "Lightness contrast and failures of constancy: A common explanation" *Perception & Psychophysics* **43** 415–424

Gilchrist A, Kossyfidis C, Bonato F, Agostini T, Cataliotti J, Li X, Spehar B, Annan V, Economou E, 1999 "An anchoring theory of lightness perception" *Psychological Review* **106** 795–834

Heinemann E G, 1955 "Simultaneous brightness induction as a function of inducing- and test-field luminances" *Journal of Experimental Psychology* **50** 89–96

Heinemann E G, 1989 "Brightness contrast, brightness constancy, and the ratio principle" *Perception & Psychophysics* **45** 89–91

Whittle P, 1992 "Brightness, discriminability and the 'Crispening Effect'" *Vision Research* **32** 1493–1507